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SINKING LARGE-DIAMETER DRILL HOLES
LAKE SUPERIOR DISTRICT UNDERGROUND IRON MINES

BY

ERNEST W. JOHNSON AND FRANK E. CASH

I.C. 7354,
February 1946.

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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By Ernest W. Johnson[2] and Frank E. Cash[3]

CONTENTS

	Page
Introduction	2
Acknowledgments	3
Borehole openings	3
Zenith mine borehole	4
Preliminary planning	4
The drill and its controls	4
Operation of the drill	5
Drilling cycle	5
Draining hole	6
Working force	6
Drilling progress	6
Safety	8
Enlargement of the borehole	9
Cary mine borehole	9
Preliminary planning	9
Surface and underground preparatory work	9
Departures from procedures followed in sinking Zenith hole	9
Formation	10
Drifting of the hole	11
Drilling progress	11
Safety	11
Enlargement of the borehole	12
Reamed churn-drill openings	12
Openings at the Hiawatha No. 1 mine	13
Hole 1	14
Reaming the pilot hole to a 30-inch diameter	14
Hole 2	15

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[1] The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is made: "Reprinted from Bureau of Mines Information Circular 7354.

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CONTENTS (cont'd.)

Page
Openings at the Hiawatha No. 1 mine (cont'd.)
Hole 3 16
Hole 4 16
Sherwood mine opening 17
Spies-Virgil mine opening 18
Safety 19
Summary 19

ILLUSTRATIONS

Fig.		Follows Page
1.	Core drill	4
2.	Concrete starting collar	4
3.	Inside drill cabin	4
4.	Sinking bucket	4
5.	Core puller	4
6.	Side channel in borehole	4
7.	Drill rig for channel	10
8.	Channel drilled	10
9.	Blocks from channel	10
10.	Churn drill	10
11.	20-inch churn-drill bit	12
12.	48-inch reamer	12
13.	Heating drill bits	12
14.	Dressing drill bit	12
15.	Building up reamer	12
16.	30-inch reamer	12
17.	Location of holes 2 and 3	14
18.	Shaft lining	18
19.	Installing 7-foot steel casting	18

INTRODUCTION

In most underground iron mines in the Lake Superior district the active workings are at considerable depth. When additional openings into such mines are needed, operating officials are eager to discover more efficient methods of constructing them.

In recent years, openings into two mines in the district were made by the borehole method, which employs chilled-iron shot as the cutting medium. Others were made by the churn-drill method, in which a pilot hole is churn-drilled and subsequently reamed to a desired but relatively small diameter. Both methods are comparatively new and unique, at least in some phases and in their application.

The purpose of this report is to present information obtained during construction of some mine openings by these methods at iron mines in the

Lake Superior district. The finished openings are referred to in the district as "boreholes," "drill holes," "holes," and, perhaps more accurately, as "shafts."

ACKNOWLEDGMENTS

The authors gratefully acknowledge the information and assistance given and the numerous courtesies extended to them by the following mining companies and their officials:

The Cleveland-Cliffs Iron Co.
The M. A. Hanna Co.
Inland Steel Co.
Layne-Northwest Co.
Pickands, Mather & Co.

BOREHOLE OPENINGS

A borehole opening was made into the Zenith mine, on the Vermillion iron range at Ely, Minn., in 1938. Another borehole was started at the Cary mine on the Gogebic iron range, near Hurley, Wis., in 1942, and was completed in 1944. Both mines are operated by Pickands, Mather & Co.

Several articles have been published[4/] describing the sinking of the Zenith borehole and, in less detail,[5/] the Cary borehole. Much of the information contained in this report was taken from these articles. Supplementary information was obtained from mining company officials.

The purpose of this report is to describe comprehensively, through the use of tables, photographs, and descriptions, the various phases of the sinking of both boreholes and of the problems encountered and their solution.

[4/] Newsom, J. B., and Haselton, W. D., Borehole at the Zenith Mine, Ely, Minn.: A.I.M.M.E. Tech. Pub. 1068; read the the New York meeting, Feb. 1939.
Richards, B. S., Sinking a Ventilation Bore Hole in Minnesota: Min. Cong. Jour., Oct. 1938, pp. 28-31.
Skillings, David N., Drill Great Ventilation Bore at Zenith Iron Mine; Skillings' Min. Rev., July 2, 1938, p. 1.
Eng. and Min. Jour., New Advance Scored in Boring Holes of Large Diameter: October 1938, pp. 39-41.
Skillings' Min. Rev., Zenith Mine Ventilation Bore Hole, Ely, Minn.: May 4, 1940, pp. 1-2.
Skillings' Min. Rev., New Shaft for Veteran Zenith Mine, Ely, Minn.: July 26, 1941, p. 1

[5/] Skillings, David N., Cary Mine Bore Hole Reaches its Objective May 12, 1944 - Deepest Bore Hole of Its Kind: Skillings' Min. Rev., May 27, 1944, pp. 1 and 11.
deRubeis, Peter, Plumbing Survey of Cary Mine Bore Hole: Skillings' Min. Rev., Aug. 19, 1944, pp. 1, 2, 4, and 6.

ZENITH MINE BOREHOLE

Preliminary Planning

In 1937, Zenith mine officials concluded that a required 50,000 c.f.m. of air to ventilate the mine could economically be forced through a smooth, circular opening 5-1/2 feet in diameter to the required depth.

Following examination of various methods that might be employed in making an opening of this size and depth and having a smooth lining to reduce friction of the ventilating air currents, it was decided that the boring system developed by the Idaho Maryland Mines Corporation of California[6] was the most suitable. As the proposed hole would be in greenstone, which is fairly hard and self-sustaining when not fractured by explosives a permanent opening requiring no support and costing virtually nothing to maintain would be provided.

An arrangement was entered into with the Idaho Maryland Mines Corporation and J. B. Newsom, owners of the patents covering the method of drilling to be used, to drill a hole from the surface to the fourteenth level, a depth of 1,208 feet.

The Zenith hole was to be 6 inches larger than the one drilled in California. Profiting from previous experience, 3 months were spent in redesigning and building the new boring equipment.

The Drill and Its Controls

The drill has two parts, upper and lower, as shown in figure 1. The upper part, or drill cabin, contains the motor, gears, controls, jacks, and a supply of 3/32-inch chilled gray-iron shot. The lower part is the core barrel, having a cutting shoe at the bottom, which is a ring of soft steel 1-1/2 inches thick with a series of slanted slots in the lower edge to feed the shot along the bottom of the shoe.

Controls for operating the drill are in the cabin. They consist of the motor-starter button, an ammeter, a weight-control mechanism, and the shot-feed box and its feeding mechanism. By watching the ammeter and listening to the sound made by the cutting shoe, an experienced operator can judge whether the drill is working satisfactorily. The weight pressure exerted on the cutting shoe is adjusted by turning an adjustment wheel which operates a winch to raise or lower the core barrel. A weight-indicator dial is watched in making this adjustment. Drilling shot are contained in a box near the operator's left hand. The shot-feed mechanism is calibrated to show the amount of shot fed to the cutting shoe each time the feed lever is operated. The controls permit operation of the drill with a minimum of guessing. Constant small adjustments in the operation of the drill are necessary because of the variation in ground conditions encountered.

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[6] Newsom, J. B., and Jackson, C. F., Shaft Sinking with a Shot Drill, Idaho Maryland Mine, Grass Valley, Calif.: Bureau of Mines Information Circular 6923, 1936, 10 pp.

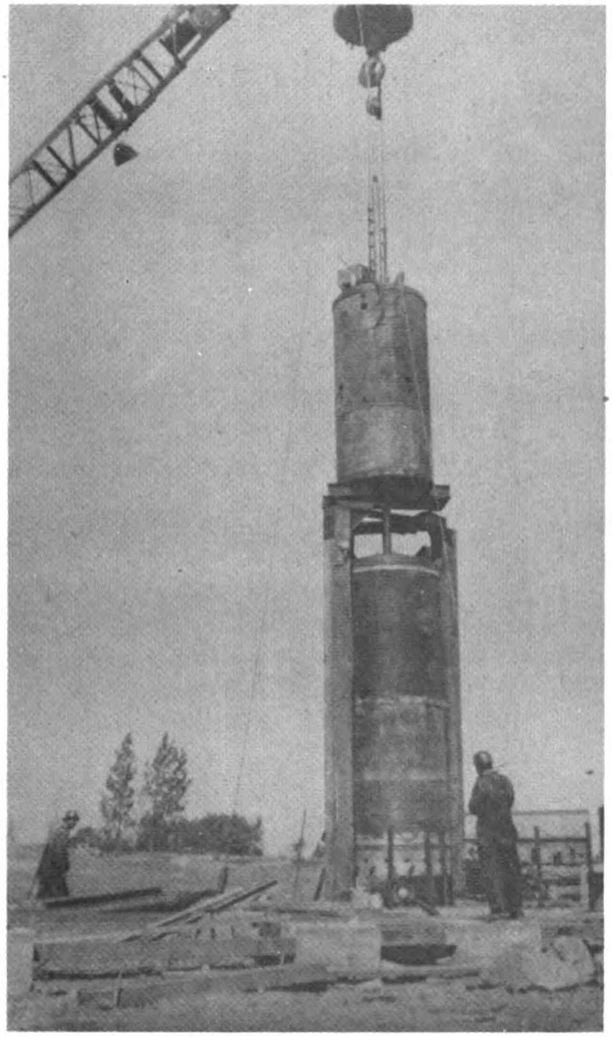

Figure 1. - Core drill.

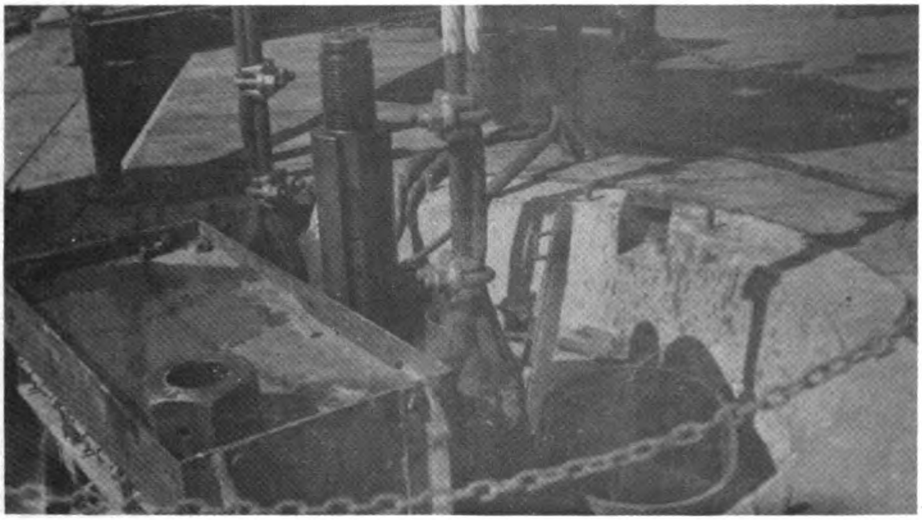

Figure 2. - Concrete starting collar.

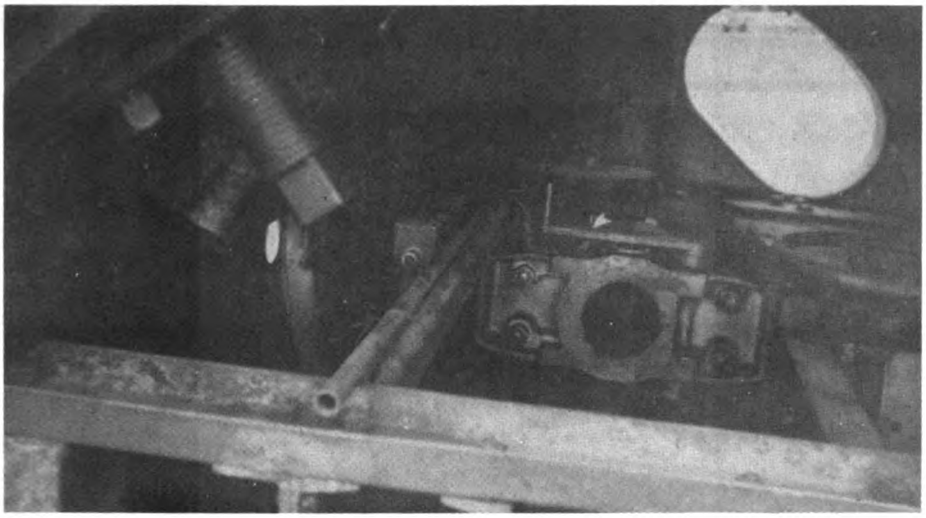

Figure 3. - Inside drill cabin.

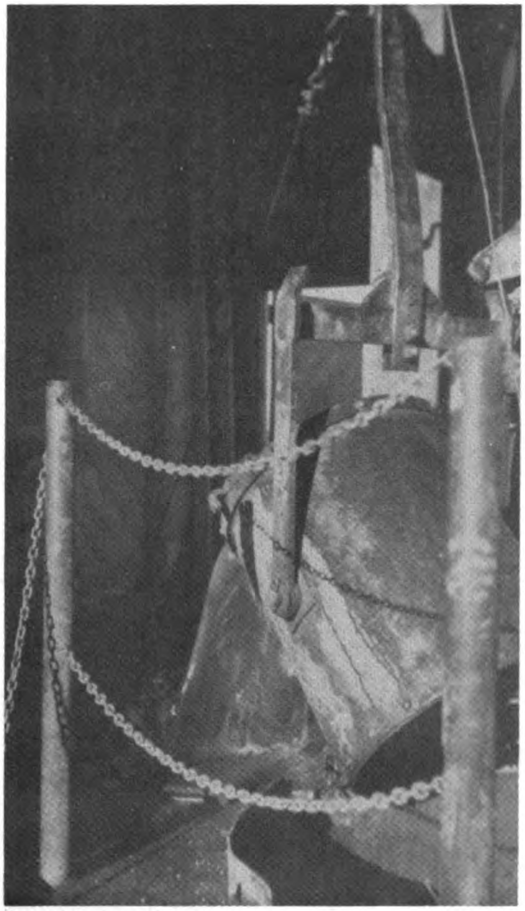

Figure 4. - Sinking bucket.

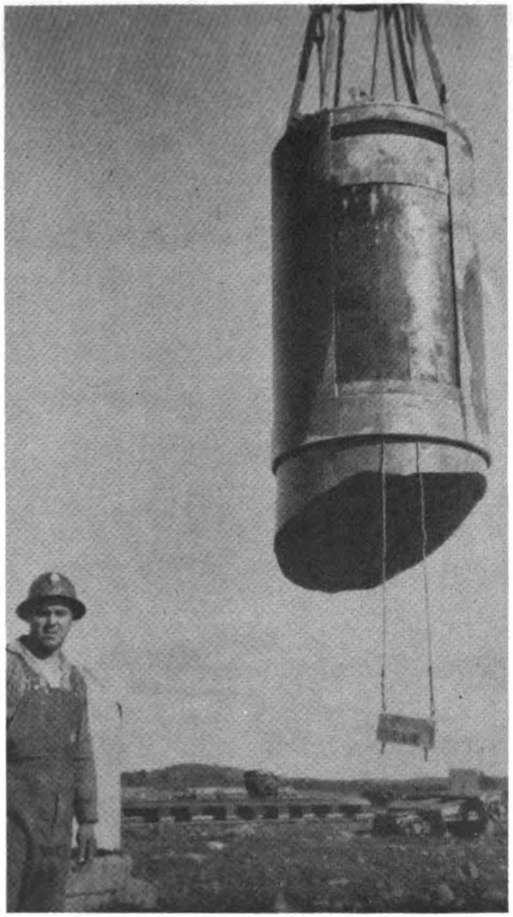

Figure 5. - Core puller.

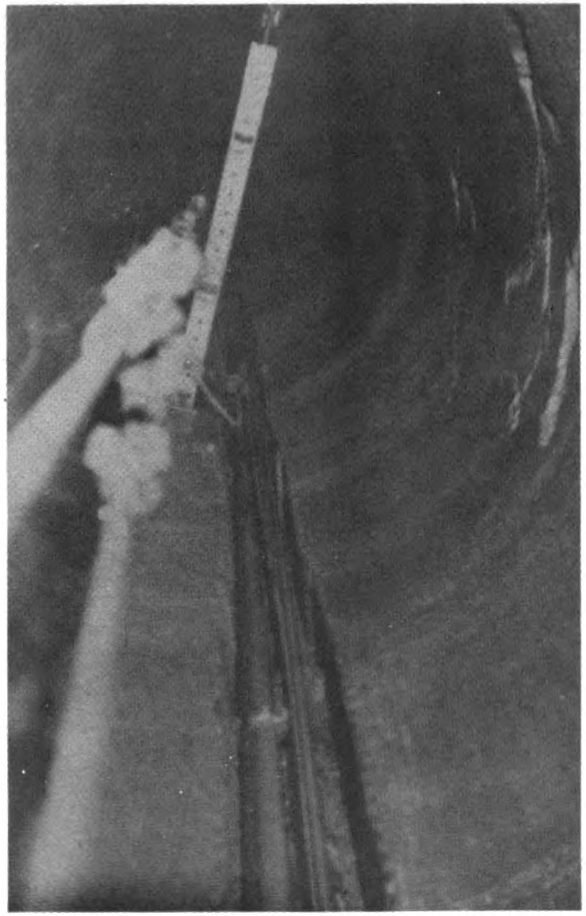

Figure 6. - Side channel in borehole.

The combined cabin, core barrel, and cutting shoe is approximately 30 feet long and weighs about 15 tons.

The mechanical equipment used in boring the hole is well described in a paper by Newsom and Haselton.[4] Nearly all of this equipment was used later in boring the hole at the Cary mine.

Operation of the Drill

Preparatory to drilling, a starter hole 15 feet deep and 5-1/2 feet in diameter was dug in alluvium and lined with concrete (fig. 2), which served as a guide for the drill and assured starting a plumb hole. The drill was then lowered into the collar, and boring was commenced.

The drilling shot were fed down the outside of the core barrel and worked their way to the cutting shoe where they were caught by the slots. The slots led to the lower edge of the shoe and carried the shot directly under the cutting edge. As the shot were much harder than the low-carbon steel cutting shoe, pellets became embedded in the bottom of the cutting shoe as it turned, scraping and abrading the rock. Thus, as the core barrel was rotated, it cut a circular slot about 2 inches in width around the core.

Drilling Cycle

A typical cycle of the drilling operation was as follows: The drill was set in the bottom of the hole, and the power cable and air hose were lowered. Then the operator was lowered in an enclosed man cage and entered the drill cabin through a trap door (fig. 3) in the top. The three jackscrews, one of which is shown in figure 3, were tightened, the power cable was connected, and the air hose was threaded into the machine so that the operator would be assured of a supply of fresh air while drilling. When ready, he signaled for power and started the drill. Drilling continued until the core barrel was filled or until a slip of rock or other operating condition stopped him, usually within 8 to 10 feet. The drilling rate ranged from 6 inches an hour in chert to over 2 feet an hour, at times, in greenstone.

At this point power was cut off, the power line was disconnected and pulled up, jacks were loosened, and the operator ascended to the surface in the cage. The drill was then hoisted to the surface and, after being inspected to ascertain whether repairs were needed, was set away from the collar. During drilling, seepage water was not removed, so that the next operation was to bail out the accumulated drill sludge and water.

Next, the core was broken off by wedging it to one side with hand-driven wedges. The operator then ascended to the surface, and the core puller (fig. 5) was lowered to the bottom. The puller was equipped with a series of serrated dogs inside a tapered ring, so arranged that when a ring was lowered over a core the dogs slid down, but when the puller was raised the dogs contracted and gripped the core.

After the core had been removed, the remaining water and sludge in the hole was bailed out, and a final trip to the bottom was made by the operator to remove broken rock and make sure the hole was clean in preparation for the next cycle. Owing frequently to an uneven bottom, some water and sludge was hand-bailed into a bucket and hoisted to the surface (fig. 4).

Draining Hole

As the hole was deepened, the flow of water increased until, at about 400 feet, it amounted to approximately 10 gallons a minute. A bailer of 260 gallons capacity, equipped with a clack valve, had been used. A new bailer of 750 gallons capacity was constructed, which was equipped with an electric pump mounted below the tank. This apparatus reduced the bailing time from 40 percent to about 25 percent and had the further effect of making it possible to keep the hole free of water for 2-hour periods, long enough to complete any ordinary operation at the bottom.

Working Force

The work of designing, assembling, and erecting the equipment was completed in March 1938, and drilling began on April 1, 1938. Three experienced drill runners were employed, who trained local men in their duties.

During the employee-training period, which included all of April, two 8-hour shifts a day were worked; thereafter the work was carried on continuously on three 8-hour shifts.

The drilling crew consisted of two men - a drill runner, who worked in the hole, and a helper, who worked on the surface. The helper operated the hoists and did other required work in connection with the surface equipment. In addition, there were a foreman, a truck driver, and a helper who worked part time, surface men who assisted at times in getting water away from the derrick storage space, shopmen, and some others.

Drilling Progress

Drilling speed was found to depend to a large extent on two variables for a given r.p.m. - (1) the rate of feeding the shot and (2) the weight exerted on the cutting shoe. On the proper combination of these two variables depended the drilling speed and, in a large measure, the success of the work.

In the following table are given figures used in arriving at the average footage drilled per day and similar data for the "best record" drilling period: -

TABLE 1. - Progress data

	Hole average	Best record
Period covered, days..............	205.5	21
Depth at start of drilling, feet..	15	494
Depth at end of drilling, feet....	1,208	693
Depth sunk, feet..................	1,193	199
Average per day, feet.............	5.81	9.5

An analysis of man-hours worked follows:

Crew hours worked: 4,933.

Man-hours, direct crew only: 11,044; multiplying factor: 2,238.

Total hours charged to the job, including foreman, during sinking period only: 15,320; multiplying factor: 3.105.

In the following table are given percentages of total sinking-period time consumed by the various phases of the drilling operation and similar data for the best-record period:

TABLE 2. - Progress data

	Hole average, percent	Best record, percent
Setting and removing drill....	9.44	9.88
Drilling......................	23.24	24.51
Bailing.......................	25.42	29.25
Mucking broken cores..........	12.83	12.25
Pulling cores with puller.....	11.62	14.23
Changing drill shoes..........	2.92	4.35
Lost time.....................	14.53	5.53
	100.0	100.0

During the last 714 feet of hole drilled, an average of 32 pounds of shot was consumed per foot of hole.

During the best-record period, an average of 22 pounds of shot was consumed per foot of hole drilled.

During the best-record period, 2.53 crew-hours per foot were expended; the average for the hole was 4.13 crew hours.

General performance data are as follows:

Hole size, 5-1/2 feet in diameter, 1,208 feet in depth (1,193 bored, plus 15 alluvium).

Started April 1, 1938, finished October 30, 1938.

Man-hours, 11,044; crew-hours, 4,933; crew-days, 205.5.

Average advance per day, 5.8 feet (177 feet per month); best week, 77 feet.

Drilling speed, 2.05 feet per hour during best week; number of drill cycles, 141; length of average cycle, 8.46 feet; time consumed by average cycle, 35 hours.

The drilling progress by months and notes on conditions prevailing during the respective months are shown in the following table:

TABLE 3. - Monthly operational data

Month	Feet of hole drilled	General conditions
March	15	Collar, alluvium; dug by hand.
April	105	Operated 557 hours training helpers and learning how best to drill the ground.
May	214	Operated full time, but still slow because the best combination of weight and shot was unknown. Also delayed by many vertical fractures in the ground.
June	120	Water problem becoming serious.
July	240	Water problem solved by use of pump and tank. During the last 21 days of July, the hole was deepened 199 feet. Did not work on July 4.
August	136	Went through quartzite, cherts, and acid diorites.
September	205	Encountered loose ground at the end of the month.
October (30 days)	173	In loose ground
Total	1,208	

Safety

From the beginning of preliminary work to the end of boring operations, 15 accidents were reported, only one of which involved a loss of time, amounting to 8 days. The types of accidents were falls of persons, 2; falls of objects, 1; squeezes, 3; burns, 2; handling of cable, 3; compressed air, 1; ladder, 1; and handling rock, 2. All of the accidents occurred before boring operations began, during which there were 3,721 man-hours of exposure. During the boring period there were 15,320 man-hours of exposure for a total to the end of that period of 19,041 man-hours. Data covering the dismantling period are not available. The severity and frequency rates of the one lost-time accident for the combined preliminary and boring operations were, respectively, 0.42 and 52.52. The frequency rate, which may appear high, was based on the relatively small number of man-hours of exposure.

Enlargement of the Borehole

An air fan, installed on the surface as planned, forced 50,000 c.f.m. of air through the hole for ventilating the mine. It continued to serve as an air-supply shaft until about the middle of 1941, when a decision was made to enlarge it into a 5-compartment, steel-supported production shaft. The enlarging process was started on the surface and progressed downward.

The borehole provided four distinct advantages in the sinking work: (1) There was ample ventilation of the shaft at all time, and explosives smoke following a blast cleared quickly; (2) breaking the ground was made easier; (3) the shaft bottom was advanced in the shape of an inverted frustum of a cone, so that most of the blasted rock fell into the hole and was loaded from a chute below; (4) there was no water problem.

The enlarged borehole is now serving as a main hoisting shaft, a supply shaft, and an exhaust-air shaft.

CARY MINE BOREHOLE

Preliminary Planning

Because of the success attained in sinking the Zenith mine borehole and in later enlarging it into a main hoisting shaft, the mine management decided to provide a similar new hoisting shaft at the Cary mine. The same drilling equipment was to be used and a hole of the same size (5-1/2-foot diameter) sunk. The completed shaft was to be bottomed at the 31st level, 2,587 feet below the collar; the size of the excavation was to be 13 by 21 feet. The contemplated borehole would be over twice the depth of the Zenith hole.

Surface and Underground Preparatory Work

Leveling the ground for the proposed borehole, shaft, and mine-plant site was begun early in the summer of 1942. Installation of the hoists and other drilling equipment took time, so that actual boring was not started until about September 15.

While boring was progressing, a drift was being driven on the 31st level to connect with the projected bottom of the borehole. When this point was reached, a raise 100 feet in height was to be driven to serve as a hopper for rock blasted above when hole-reaming operations got underway.

Departures from Procedures Followed in Sinking Zenith Hole

The concrete collar was made 18 feet deep instead of 15 feet, as at the Zenith mine, for better guidance in starting a plumb hole.

Because of the great depth of hole contemplated, a change in handling the power, signal, air, and water lines was necessary, as none of these lines would be strong enough to sustain its weight for the length required if hung in the hole and raised and lowered to conform with the drilling cycle. The problem was solved by cutting a continuous channel in the side of the hole (fig. 6) as drilling progressed, large enough to contain the electric cable, a 1-inch drill-water line for use of the two air-powered percussion drills employed, a 2-inch compressed-air line to supply power for the percussion drills and for ventilation in the drill cabin, signal wires, and a small pump-discharge line to the surface from a pump station cut out of the side of the hole at a depth of 250 feet.

The channel was cut as follows: The two drills were mounted on parallel upright posts on a drill rig (fig. 7) suspended by the hoisting rope. Two jacks on the drill rig were screwed against the side of the hole to stabilize the rig when the drills were in operation. Parallel series of contiguous holes 11 inches apart were then drilled, 15 inches in depth for the first 800 feet of hole and 11 inches below that. Blocks in 3- to 4-foot lengths were then extracted by drilling a line of cross holes and breaking with hand-driven wedges. These two operations are shown in figures 8 and 9. The channel was advanced as the hole was deepened, having been kept within about 125 feet of the bottom.

A 50-g.p.m. electric pump installed in the pump station previously mentioned pumped a trapped 2-1/2 g.p.m. of water seeping from the zone above to the surface. The pump was automatically controlled by a float-valve arrangement. Water that accumulated in the bottom of the borehole was removed with the 750-gallon bailer used at the Zenith, but without the electric-pump attachment, which was not required.

Core that could not be broken off by applying tension on the hoist rope when the core puller was used was broken off by means of a "time bomb." The apparatus is shown hanging from the core puller in figure 5. The bomb was charged with 1/2 stick of 60-percent dynamite. Its use was required approximately half the time. A timeclock arrangement permitted exploding the charge at any time.

The core made in the drilling operation was 5 feet 2 inches in diameter and weighed nearly 2 tons per foot.

The main hoist used at the Zenith mine was also used for the same purpose at the Cary mine hole to a depth of 1,000 feet; from that point it served as the man-hoist. A new main hoist was installed at that time, which was equipped with a 12-foot drum and was powered with two 400-horsepower motors. Nontwist 1-1/4-inch steel hoisting cable was used.

Except for the changes noted, the equipment used in sinking the Cary mine hole was the same as was used at the Zenith mine. The operating cycle, except when cutting the channel, duplicated that followed at the Zenith mine.

Formation

The Cary mine hole was sunk through fractured granite and greenstone, in which several dike intrusions 5 to 50 feet thick were encountered. This

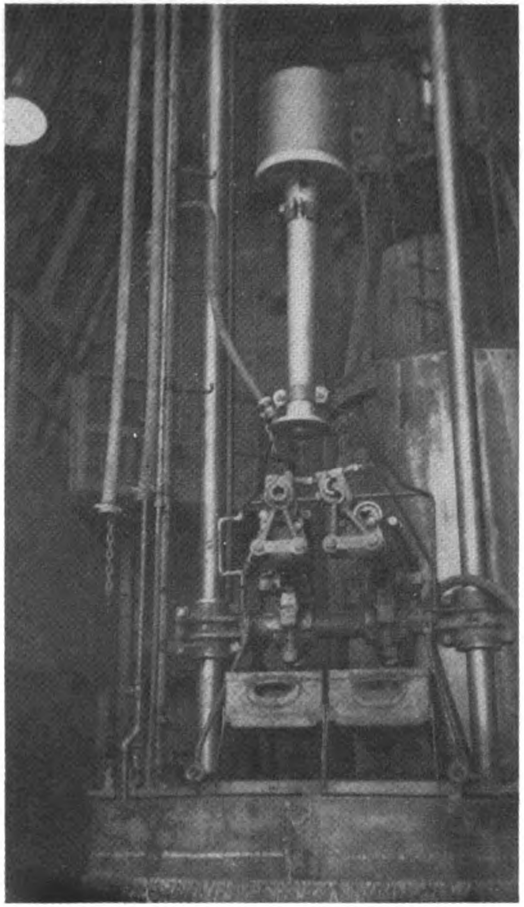

Figure 7. - Drill rig
for channel.

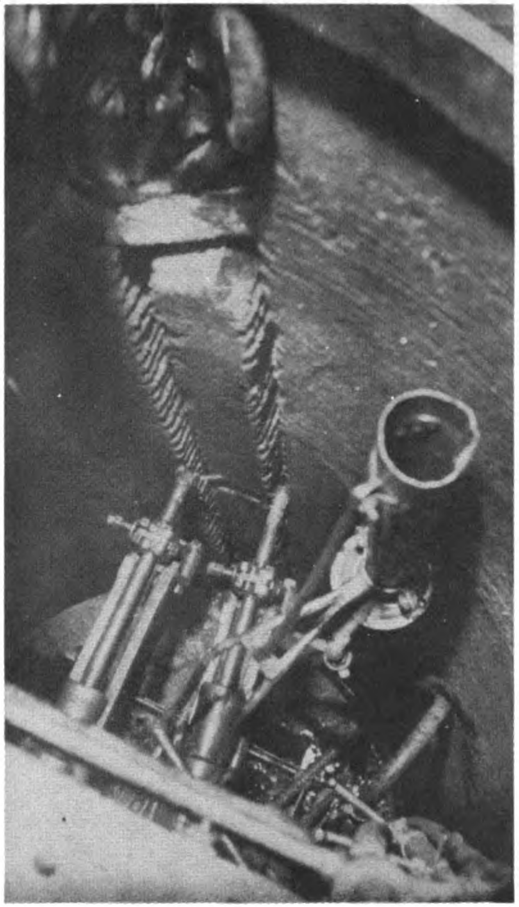

Figure 8. - Channel drilled.

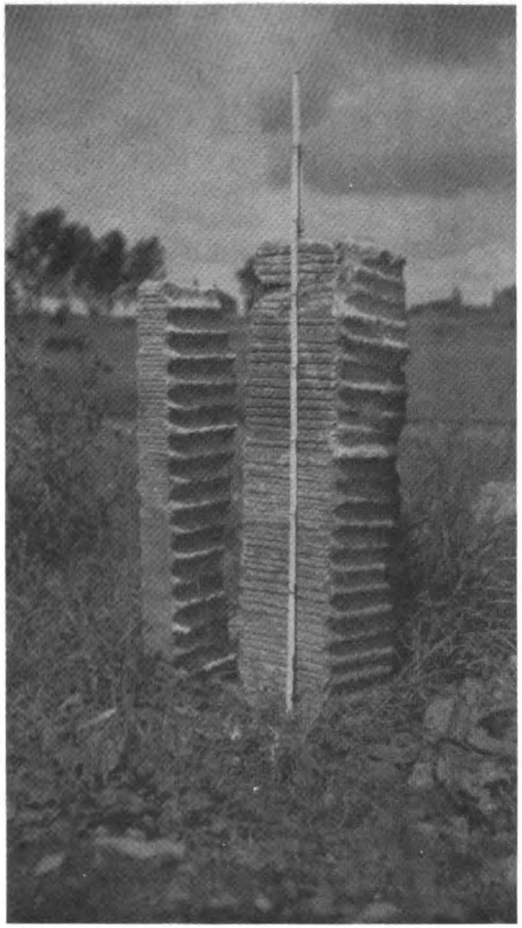

Figure 9. - Blocks from channel.

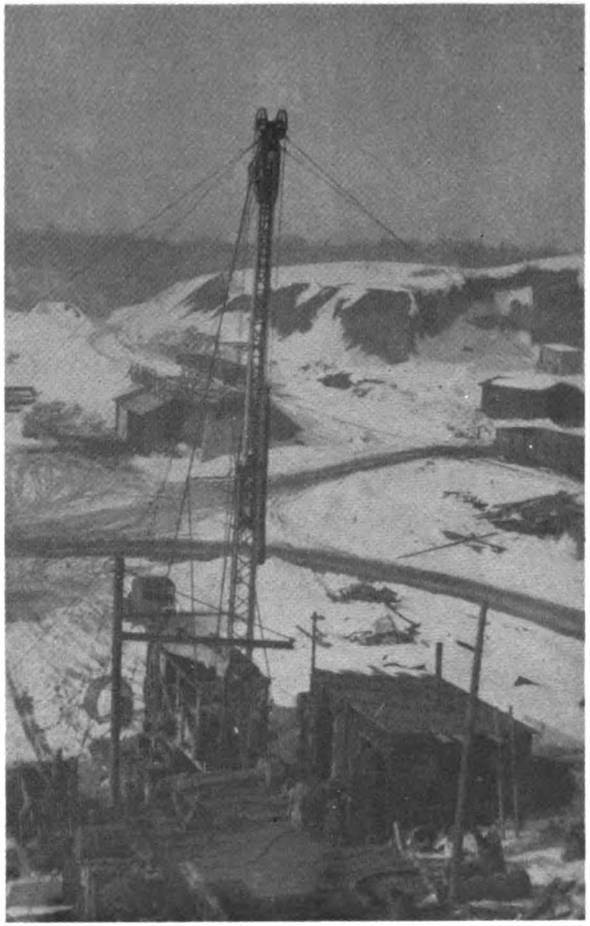

Figure 10. - Churn drill.

formation proved less favorable for drilling than the more uniform greenstone encountered in the Zenith mine hole, which was considered ideal for this type of drilling.

Drifting of the Hole

The Cary mine hole had a tendency to drift from plumb, as may be noted in the description of the plumbing survey by Peter deRubeis.[5] It advanced downward in a more or less corkscrew fashion, and at an approximate depth of 725 feet was 9 feet off plumb, which brought the outer rim of the hole to the proposed side of the shaft. Because it was believed the hole would continue in the same direction unless corrective measures were taken, drilling was temporarily discontinued while the sides of the hole were blasted and excavated sufficiently to permit installation of a concrete guide lining 30 feet long. The lining was inclined slightly off plumb toward the proposed shaft center. These measures brought the hole back toward the shaft center, and although it continued to deviate, it did not go outside the proposed shaft limits except at the bottom, when the rim of the hole was about 2 feet outside the planned shaft limit.

Drilling Progress

Detailed data such as those for the Zenith mine hole were not available. However, the following comparison of drilling speeds per calendar day from the beginning of actual drilling to its end is of interest. Drilling of the Zenith hole was started on April 1, 1938, and ended October 30, 1938, for a total of 212 elapsed calendar days. During this time, 1,193 feet of hole was drilled for an average per calendar day of 5.6 feet. Drilling of the Cary mine hole was begun September 15, 1942, and ended May 12, 1944, for a total of 605 elapsed calendar days, during which 2,482 feet of hole was drilled for an average per calendar day of 4.1 feet. Thus, the average drilling rate at the Cary mine borehole was 26.8 percent less than at the Zenith mine borehole. However, considering the harder ground at the Cary mine, the tendency of the hole to drift, the necessity of excavating a channel in the side of the hole, and last and perhaps most important, the natural loss in rate of drilling as the hole deepened, it may be assumed that the comparative efficiency attained was equivalent to that at the Zenith mine.

The number of drilling cycles at the Cary mine was 452, and the average advance per cycle was 5.49 feet, as compared to 141 and 8.46, respectively, at the Zenith mine. The reduced cycle length at the Cary mine is indicative of the absence of uniformity of the rock formation.

Safety

Including time consumed in necessary preliminary work prior to the actual start of boring operations, amounting to 505 man-hours, and 58,612 man-hours expended in the actual boring operations, a total of 59,117 man-hours was directly chargeable to the boring operation. An additional 20,000 man-hours of shop work was involved, which is not given consideration in this safety compilation because if an accident had occurred while such work was being done it would have been charged to the mine shops.

There were three accidents involving 40 days of lost time. Two of these occurred on the surface and one in the borehole. The first was a foot injury and involved 11 days' lost time; the second was a back strain from lifting and involved 16 days lost; the third occurred in the hole when the injured man was ascending on the bailing rig, which caught on the water line and pinned him between the pipe and the bail of the rig, causing chest bruises that occasioned 13 days' lost time. The resulting severity and frequency rates covering man-hours of work directly chargeable to the boring operation, are, respectively, 0.68 and 50.75.

Enlargement of the Borehole

Work of enlarging the borehole into a main shaft was started shortly after the borehole had been completed. Rapid progress is being made. The advantages of enlarging a borehole into a mine shaft instead of sinking a shaft are enumerated in the description of the Zenith mine borehole enlargement operation. They apply equally well to the Cary mine.

REAMED CHURN-DRILL OPENINGS

Churn-drill and rotary-drill openings of small diameters into shallow mines are rather common. In Arkansas large-diameter rotary-drill holes[7] have been drilled to a depth of 228 feet, but reamed churn-drill holes of large diameter, up to 48 inches, into deep mines are uncommon. As far as known, the first opening of this kind in the Lake Superior district was made in 1940 at the Hiawatha No. 1 mine of the M. A. Hanna Co., Iron River, Mich. Two similar openings were completed in this mine during the first half of 1945, and a third is being sunk.

Late in 1942, a 48-inch opening of this type was started at the Sherwood mine of the Inland Steel Co., Iron River, Mich. A 15-inch churn-drill hole is being sunk at the Spies-Virgil mine of the Cleveland-Cliffs Iron Co., also in Iron River.

Contracts for sinking all of the holes enumerated were let to the Layne-Northwest Co. of Milwaukee, Wis., by the respective mining companies. An affiliate, the Layne-Bowler Co., Inc., of Memphis, Tenn., owns the patent on the reaming process used in enlarging the churn-drill pilot hole.

With exception of the 15-inch hole at the Spies-Virgil mine, where a light, Model 39, Bucyrus-Erie drill machine is in use, a heavier, Model 36L machine (fig. 10) of the same make was and is in use in drilling the other holes enumerated. The drilling contractor believes the 36L machine is satisfactory for use in sinking holes ranging in size to a 30-inch diameter, but for larger holes a heavier machine is favored.

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[7] Platt, D. H., Shaft Sinking by Rotary Drilling: Bureau of Mines Information Circular 7336, 1945, 14 pp.

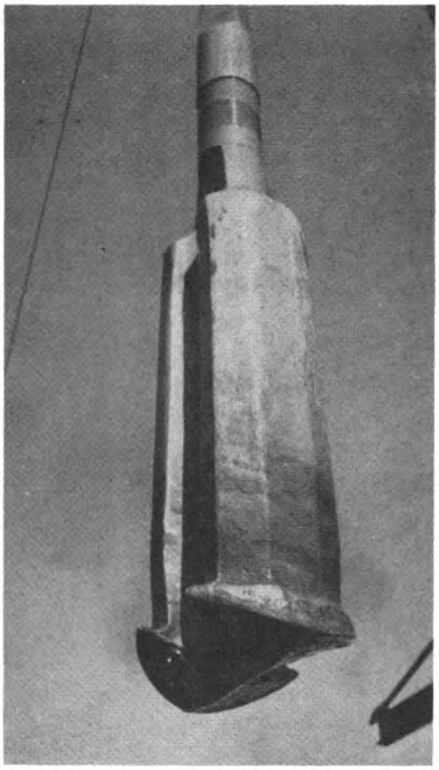

Figure 11. - 20-inch churn-drill bit.

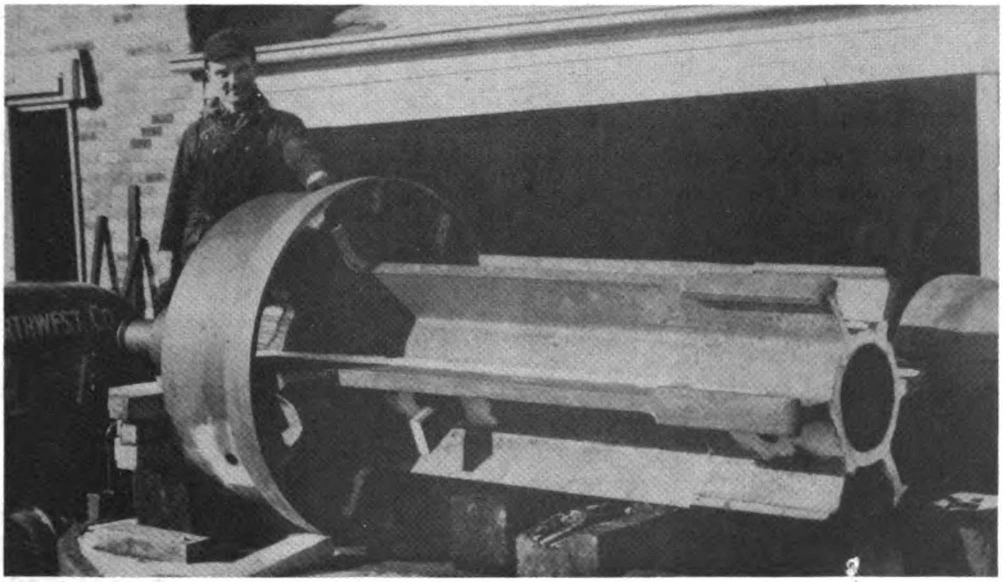

Figure 12. - 48-inch reamer.

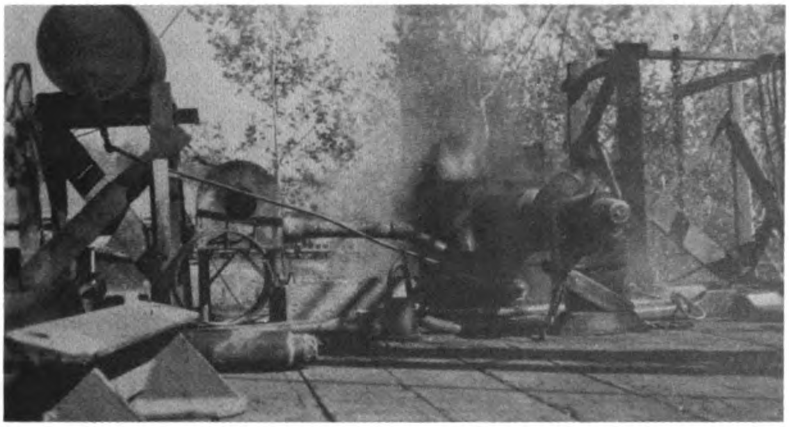

Figure 13. - Heating drill bits.

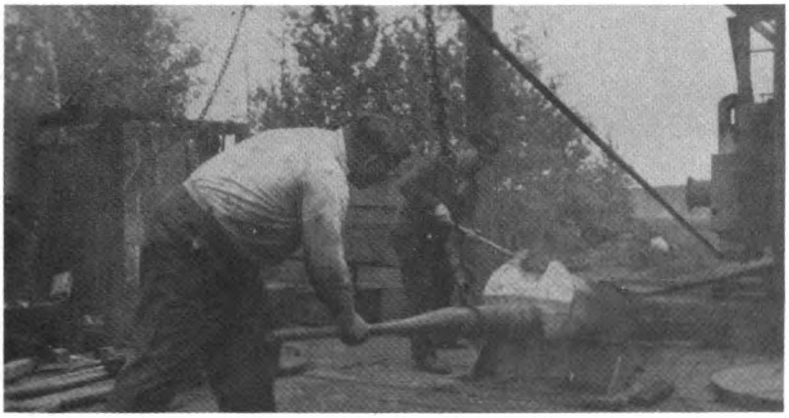

Figure 14. - Dressing drill bit.

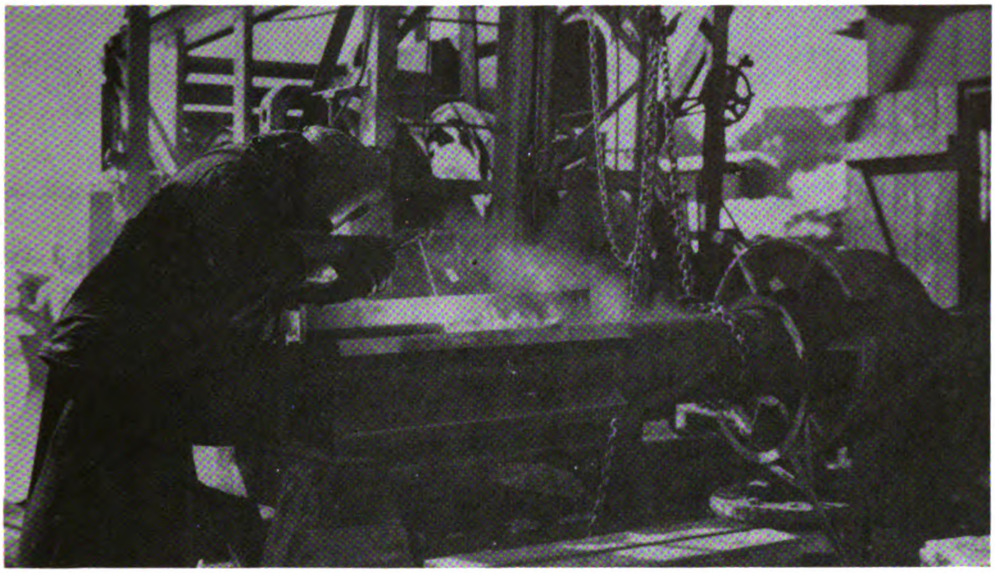

Figure 15. - Building up reamer.

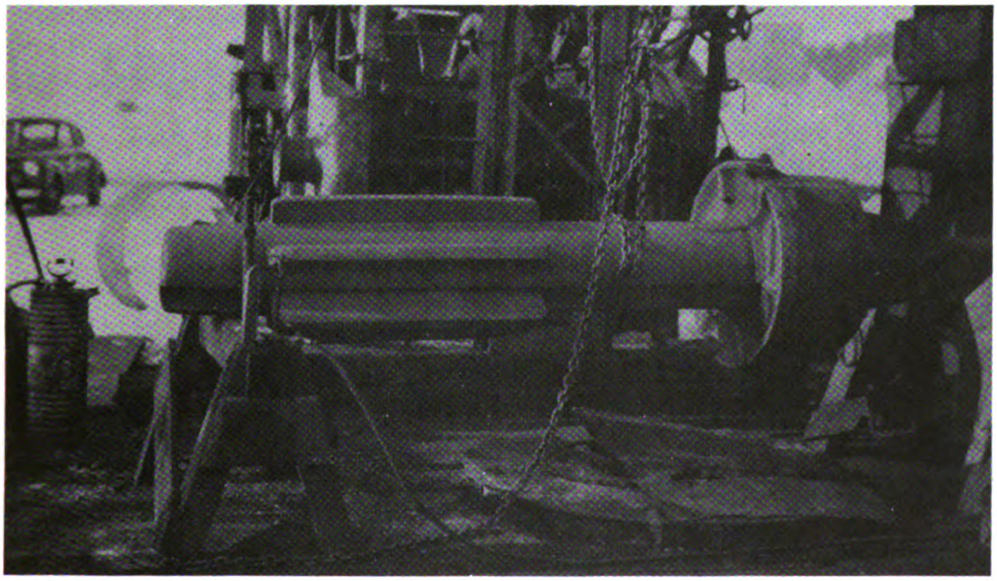

Figure 16. - 30-inch reamer.

The 36L machine is powered with a 70-horsepower Diesel engine. A 1-inch steel-cable drill is used. Its cost, together with that of the required tools to complete a large-diameter hole, is approximately $25,000.

In operation, churn-drill bits and reamers up to 36 inches in diameter require a complete string of drill tools, including drill stem, jars, and a rope socket. A 20-inch churn-drill bit, shown in figure 11, weighs about 3,000 pounds. A drill string comprised of a 20-inch bit, drill rods, jars, and a bit guide weighs approximately 8,000 pounds.

The 48-inch reamer (fig. 12) is a self-contained unit requiring neither a stem, jars, nor rope socket. It is constructed so that a jar-ring effect can be obtained, if needed, and the rope socket becomes a part of the jars. It weighs about 9,000 pounds.

Both the drill bits and reamers are dressed by the drill crews at the drilling sites. The bits are heated in open-front oil-fired furnaces (fig. 13) for dressing and tempering. When heated, the bits are hand-dressed with the aid of a suspended swinging hammer (fig. 14). The cutting edges of reamers are built up as required by welding on hard-surfacing material (fig. 15).

It requires 30 minutes to 1 hour to dress a drill bit and 6 to 10 hours to build up worn cutting edges of a reamer. Generally, when drilling in ground such as that encountered in the Iron River district, it has been found necessary to dress a bit following periods of use of 4 to 12 hours.

Where possible and practicable to do so, the pilot hole is connected with an underground opening in the mine to permit removal from below of cuttings made in reaming. However, if required, such cuttings can be removed by the bailing process used when drilling.

A drill crew is comprised of two men, a driller, and his helper.

The purposes for which the previously enumerated openings were made, and other informational data in connection with the sinking thereof, including available log data, are given in the pages to follow.

OPENINGS AT THE HIAWATHA NO. 1 MINE

Ore in the Hiawatha No. 1 mine and in other mines in and near Iron River, Mich., is generally underlain by a black slate that contains varying amounts of sulfur in the form of pyrites. Fire from spontaneous combustion sometimes results upon exposure of the black slates to air, and a poisonous (sulfur dioxide) gas frequently is given off. Two methods of controlling or preventing such fires are practiced; one is to seal off the affected area and the other is to backfill mined-out areas to cover the slates and exclude air.

At the Hiawatha No. 1 mine, where the mining method is open stoping, it was decided to cover the exposed black slates by backfilling mined-out stopes and at the same time to eliminate the danger of air blasts from sudden large-scale subsidence. Early in 1940, company officials decided that the problem of delivering backfill material to the desired locations could be solved best and most economically by sinking a 30-inch-diameter hole at a strategic location to a required depth. Sand, gravel, or other material could then be dumped into the hole and dragged with scrapers through connecting drifts to desired points.

Hole 1

A 6- by 6-foot shaft was started on January 22, 1940, and bottomed in solid rock at a depth of 56-1/2 feet on February 21, 1940. The shaft was supported with a wooden lining. A 12-inch pilot hole was then churn-drilled. Table 4 shows drilling progress, and table 5 shows the formation penetrated.

TABLE 4. - Drilling progress

Depth from collar, feet	1940	
71....................	March	4
175....................		15
350....................		19
405....................		25
600....................	April	1
700....................		3
820....................		8
950....................		11
1,004 (bottom).........		15

TABLE 5. - Ground formation

Depths from collar, feet	Material penetrated
0 - 56-1/2.....	Sand and gravel.
56-1/2 - 150.........	Black slates.
150 - 560.........	Iron formation (Fe, 35 percent).
560 - 990.........	Black slates.
990 - 1,004.........	Iron formation

The work was done by two-man crews on two 8-hour shifts daily.

Reaming the Pilot Hole to a 30-inch Diameter

The tool shown in figure 16 was used in reaming the 12-inch churn-drill hole to a 30-inch diameter. It is seen to comprise a section of a solid cylinder, which has built-up cutting edges on the lower perimeter and built-up inner radial cutting edges on the face. The cylinder is attached to a solid steel-shaft projection, which fits into the pilot hole for a guide. The shaft has three lengthwise channel depressions to permit passage of cuttings into the hole.

In operation, the reamer is alternately raised and dropped in a manner exactly similar to that followed in churn-drilling. An underground drift

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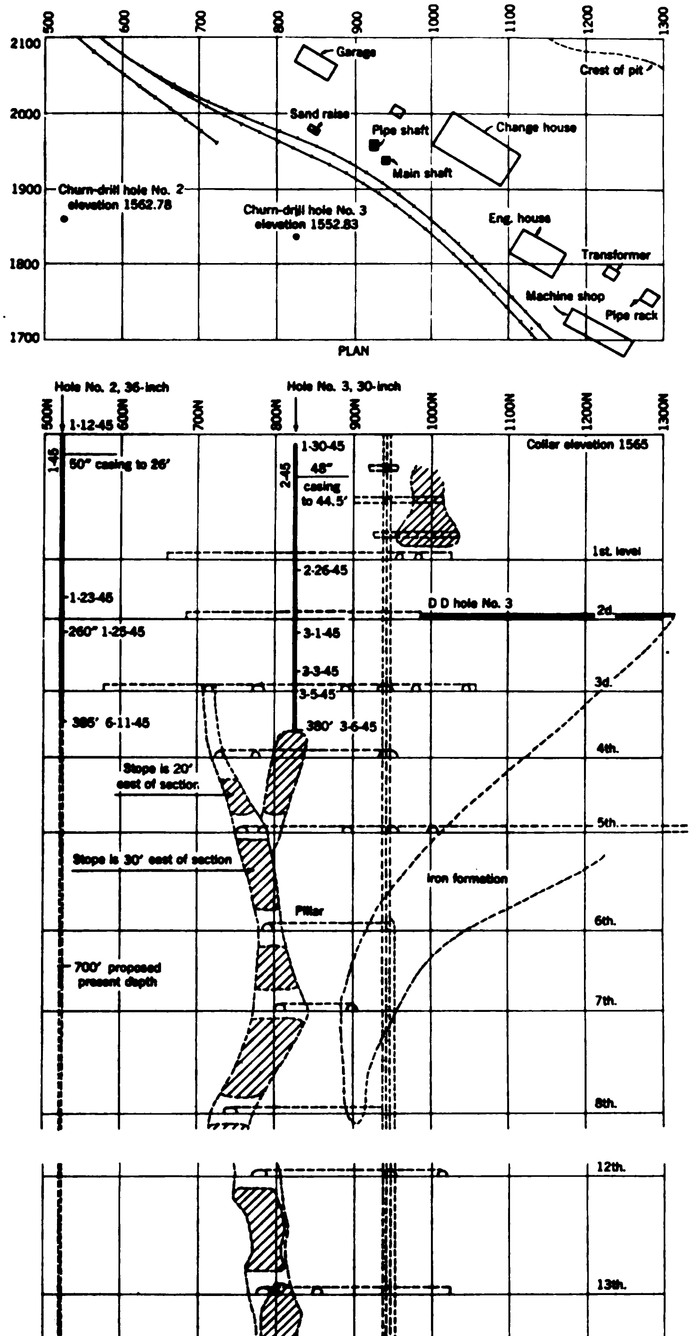

Figure 17.—Vertical cross section looking west at 1900 west churn-drill holes No. 2 and 3.

connection was made to the bottom of the hole for use in removing cuttings from the reaming operation and for later use in the transfer of backfill material.

Detailed information on the reaming operation was not kept, but a mine record shows that reaming was in progress in May 1940 and that by the end of July the hole had been reamed to a depth of 250 feet. The record shows, further, that most of August and all of September were spent in fishing for a lost tool, which lodged about 50 feet above the bottom of the 12-inch hole. It was finally recovered by drifting in from the mine workings at that elevation a distance of about 20 feet. As of October 30, 1940, reaming had progressed to a depth of 800 feet and was completed to the bottom in November 1940. The same crews and work periods were used as in drilling the pilot hole.

Hole 2

Late in 1944, Hiawatha mine officials concluded that a new opening into the mine was required for backfilling worked-out stopes in an area removed from hole 1. It was decided to sink the new opening to a depth of 700 feet for the present and to provide drift connections from the mine workings at necessary elevations. In future years, as mining operations progress downward, it is planned to deepen the opening by stages, as required, to a final depth of about 1,900 feet, as shown in figure 17.

A decision was made first to churn-drill a 19-inch pilot hole and to ream this hole in two stages, the first to a 30-inch diameter and the last to 36 inches. Because of doubt as to whether the site of the proposed hole was over subsiding ground, an 8-inch test hole was first drilled to a depth of 260 feet. The test hole was in rock formation for its full depth. It was started on January 13, 1945, and completed on January 25, 1945. Two crews of two men each worked 11-hour shifts daily. No subsiding ground was encountered and none was anticipated below the depth attained by the test hole.

A 50-inch-diameter circular shaft was next sunk through broken rock and bottomed in solid rock at a depth of 26 feet. The shaft was supported with an iron casing 3/16 inch thick. Eight- to 10-foot lengths of casing were installed and lowered as the shaft was deepened; additional lengths of casing were welded on as needed. Later, the opening outside the casing was filled with concrete.

In sinking the shaft, a round of five holes about 2 feet in depth was drilled with an air drill using compressed air piped from the nearby mine supply line. Charged holes were blasted electrically. A single 12-hour shift employing both drill crews was worked. Broken rock was hoisted in a 1/4-ton bucket with the drill-machine hoist.

While work on hole 2 was in progress, a drift from the mine workings was started to intersect the hole at a depth of 400 feet. It shortly encountered subsiding ground, and the plan of obtaining backfill material from the proposed hole at this point had to be abandoned.

Because the need of providing backfill material at this location was imperative, it was decided to stop work temporarily on hole 2 until a new opening for this purpose could be completed at a site about 300 feet to the north. This opening was to be called hole 3.

Hole 3

Employing a procedure similar to that used at the preceding hole, a shaft supported with 3/16-inch casing 48 inches in width was sunk through broken rock and bottomed in solid rock at a depth of 44-1/2 feet. Shaft sinking was completed on February 24, 1945, both drill crews having worked together on a daily 12-hour shift.

A 3/16-inch iron casing 30 inches in diameter was installed inside the 48-inch casing, after which the latter was removed, and the outside opening was filled with concrete. The additional space provided by the 48-inch casing was required in the sinking operation. It was decided to drill a 20-inch pilot hole first and then ream it to a 30-inch diameter.

As it was desired to have the hole hit the back of the open stope below, a pipe slightly larger than the drill bit was installed plumb in the shaft to serve as a guide in starting the hole. Churn drilling was started on February 27, 1945, and the hole penetrated to the stope on March 5 at 380 feet below the surface. Reaming the hole was started on the night shift of March 8 and completed on the morning of March 15. Two-man crews working 12-hour shifts daily were employed in both the drilling and reaming operations.

Following removal of the drilling equipment, a bar grizzly with bars set at 12-inch centers was installed over the hole by the mining company and backfilling was begun. Gravel and sand is loaded into trucks with a small power shovel and hauled to the hole. (Figure 17 shows a plan of and a vertical cross section through holes 2 and 3.)

Hole 4

While hole 3 was being sunk, a stope about 300 feet west of that hole began caving. It was therefore decided that before work on hole 2 was resumed, a new hole, designated No. 4, would be sunk to permit backfilling the stope in which caving had occurred.

As in the case of hole 3, it was decided to drill a 20-inch pilot hole and then to ream to a 30-inch diameter.

A shaft 48 inches in diameter and supported in the usual manner with an iron casing was started on March 20, 1945. Ten feet of alluvial material and 35 feet of broken rock were penetrated before the shaft could be completed in solid rock to a depth of 45 feet.

Churn-drilling was started on April 10, 1945. On April 15, a depth of 230 feet was attained and on the following day 300 feet. On April 14 the drill string broke at a depth of 365 feet, leaving the bit and 15 feet of drill string in the hole. Fishing tools arrived on April 17, and the lost tools were recovered the same day. Drilling was resumed, and the hole penetrated to the stope on April 21 at a depth of 525 feet.

Except for 10 feet of alluvial material, rock and iron formation were encountered to a depth of 285 feet and black slate below that. Reaming the hole to a 30-inch diameter was started on April 24 and reached a depth of 205 feet on April 26. On May 9 a depth of 500 feet was attained. At this point the reamer stuck in the hole and could not be loosened by any available local means. A fishing tool arrived from Tulsa, Okla., on May 14, and with it the reamer was recovered on May 15. However, it stuck again on the same day and could not be recovered again until May 17. The hole was completed on May 22. Drilling of hole 2 was resumed early in June 1945.

SHERWOOD MINE OPENING

In 1942, at a time when the Sherwood mine was being developed, a relatively quick means of supplying ventilation air to the mine was sought. Because of the success attained in sinking the 30-inch-diameter hole at the neighboring Hiawatha mine, Sherwood mine officials arranged with the same contractor to drill a similar hole at their mine, but of a considerable larger diameter if possible. The contract price was on a per-foot basis and varied as to diameter but did not require finishing the hole to a given large diameter, as a diameter larger than 30 inches would have been experimental.

A 5- by 5-foot shaft was started on September 1, 1942, which penetrated 132 feet of alluvial material and 11 feet of broken rock at the bottom before encountering solid rock where drilling could be started. The shaft was supported temporarily with a wooden lining.

Drilling was commenced promptly, a 12-inch pilot hole being completed at 1,000 feet early in November. The remainder of November was taken up in cementing the sides of the hole between the 230- and 300-foot depths to seal off a flow of water in that horizon.

Reaming the hole to a 30-inch diameter was started about December 1 and had progressed to 365 feet late in the month, when the reamer broke. It was found necessary to construct a new reamer, and because of war priorities there was considerable delay in obtaining the necessary materials. For this reason the reaming operation was not resumed until late in February 1943. It was completed to the desired 930-foot depth in March 1943.

The second stage of reaming, to a 48-inch diameter, was started in March 1943, and a depth of 487 feet was attained in that month, when the reamer broke. Further thought of continuing the reaming to this diameter was abandoned when it was learned that, because of war priorities, it would probably require 5 to 6 months' time to get needed materials for the construction of a new reamer.

The various ground formations encountered in sinking this hole are shown in table 6.

TABLE 6. - Ground formation

Depth, feet	Ground formation
0 0 - 132	Sand and gravel.
132 - 143	Broken, cherty iron.
143 - 220	Hard, cherty iron.
220 - 240	Broken, lean ore.
240 - 590	Hard, cherty iron.
590 - 800	Fairly hard, black slates, with seams of cherty material.
800 - 1,000	Very hard, cherty iron.

At its intersection with the 400-foot level the hole was plumb, at the 650-foot depth it was 1 foot off plumb, and at the 1,000-foot level it was 12 feet off plumb.

No blasting was required in either the drilling or reaming operation.

Following completion of the hole, a 1/4-inch thick, round, steel casing 54 inches in diameter was installed in the shaft. The outside space was filled with concrete.

A ventilating fan was installed near the drilled hole on the 920-foot sublevel. It is operated blowing and draws a supply of fresh air from the surface through the hole.

SPIES-VIRGIL MINE OPENING

Late in 1944, officials of the Spies-Virgil mine concluded that additional ventilating of a newly developed extension of the ore body could best be accomplished by sinking an air shaft from the surface in that area. The shaft would also serve as an emergency exit.

To facilitate the shaft sinking, it was decided first to sink a 15-inch-diameter drill hole from the surface to intersect an inclined raise approximately 560 feet below. A contract for sinking the hole was let to the Layne-Northwest Co.

Work on the hole was started early in 1945. Following their customary procedure, the contractor first sank a small shaft to 95 feet, where solid rock was encountered. The shaft was supported with a wooden lining (fig. 18). A 7-foot-diameter steel casing (fig. 19) was then installed, and the space between it and the outer wooden lining was filled with concrete.

Drilling of the 15-inch-diameter hole was then commenced. At 140 feet below the surface the drill bit jammed, owing to an abrupt deviation of the hole from plumb. This deflection was caused by the steeply dipping rock formation, which is comprised of hard and soft layers, and a resulting tendency of the drill bit to advance faster on the soft-seam side and "slide" along the hard seam.

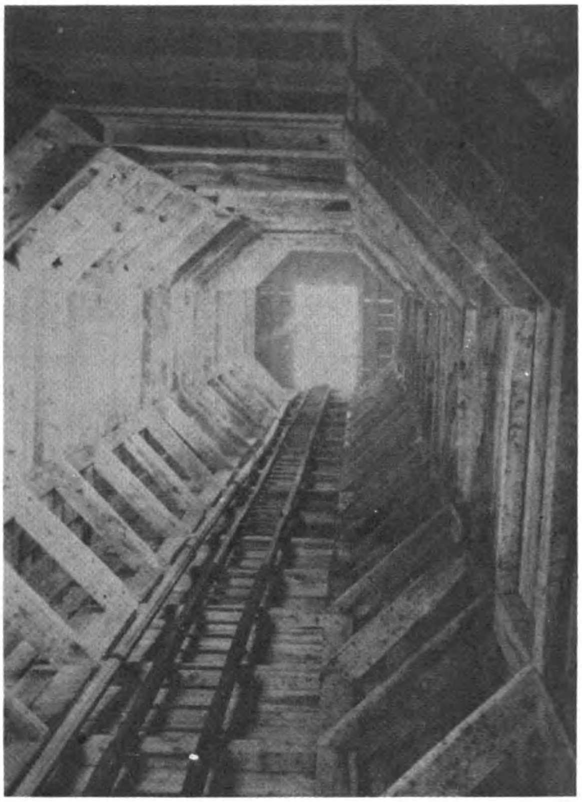

Figure 18. - Shaft lining.

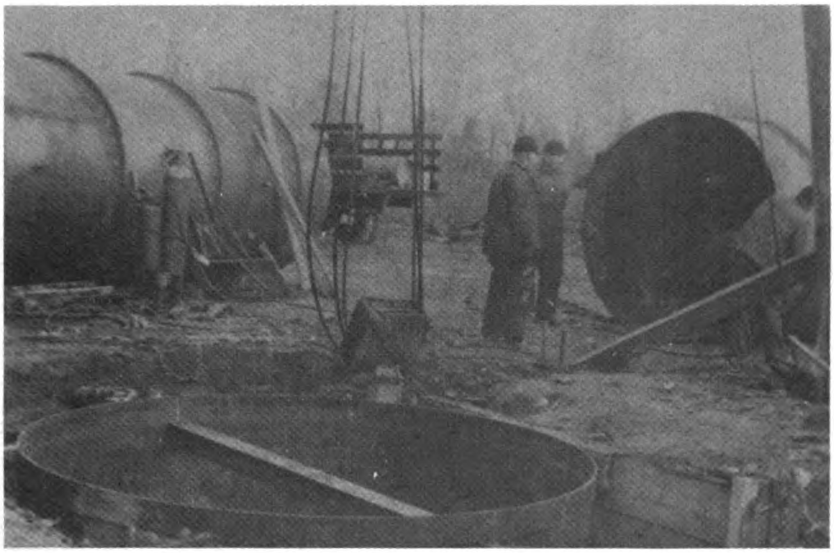

Figure 19. - Installing 7-foot steel casing.

The customary procedure of installing a plumb-pipe guide in the shaft inside of which the drill string could be operated was not followed. Had this been done, it is believed the hole would have progressed plumb.

After attempts at continuing the hole with the aid of blasting failed, an 8-inch bit was substituted, and the desired depth of 560 feet was attained without too great difficulty. However, although deep enough, the hole did not intersect the underground opening, obviously because it had drifted. The noise made in drilling was heard clearly by listeners underground, but it seemed impossible to determine the source of the noise, as repeated attempts at "holing through" failed. After some delay, a home-made apparatus was used containing a compass immersed in a liquid that jelled after a short time and retained the compass needle in its position, and a glass tube containing an acid to mark the glass, indicating the degree of dip at a desired point. Readings at desired depths were taken, and calculations made from the information obtained indicated that the hole had drifted 33 feet in a southeast direction. A connecting raise was then driven.

A 15-inch-diameter reamer was used in finishing the hole to that size, the work having been completed on June 7, 1945.

Ordinarily, a hole of this size and depth would be completed in much less time than was actually required. This is clearly indicated by the logs of the holes previously described. Additional reasons for delays in the drilling operation were inability to operate the drill on more than one shift for the greater part of the time because of a shortage of drill runners, protracted waiting for repair parts for the drilling machine, and about two weeks' illness of the drill runner. An actual day by day log of the hole or other similar record was not kept.

Safety

Only one lost-time accident occurred, involving 2 days during the sinking of holes 1, 3, 4, and, to June 11, 1945, hole 2 at the Hiawatha No. 1 mine and the holes at the Sherwood and the Spies-Virgil mines. The accident caused a strained shoulder. The number of man-hours worked was not available. The safety record up to that time obviously was good.

SUMMARY

Two 5-1/2-foot-diameter boreholes, one at the Zenith mine and one at the Cary mine, were sunk to respective depths of 1,208 and 2,487 feet with chilled iron shot as the cutting medium. The shallower hole was the first of its kind to be sunk in the Lake Superior district and served its intended purpose as an intake air shaft for several years, until later planning required enlargement for use as a hoisting shaft. Enlargement of the hole and installation of shaft timbers proceeded rapidly, the shaft being completed in a short time.

Sinking of the borehole at the Zenith mine proceeded smoothly, with little or no difficulty except from water seepage, which at 400 feet amounted to 10 gallons a minute and required 40 percent of the time for unwatering. Use of a larger bailer equipped with an electric pump for complete filling reduced the time required for unwatering to 25 percent.

As had been anticipated, the greenstone formation penetrated proved ideal for this type of drilling, as it was uniform in structure, not too hard, and self-sustaining.

Because the advantages of a pilot hole in shaft sinking had been demonstrated at the Zenith mine, Cary mine officials decided to follow a similar procedure in sinking a new shaft at that mine. Boring equipment used at the Zenith mine was moved to the Cary mine for this purpose.

Owing to the greater depth of the Cary mine borehole and the resulting impracticability of reeling and unreeling the power and signal lines from the surface, as at the Zenith mine, a channel to contain the lines was made in the side of the hole with two percussion drills. Another departure from practice at the Zenith mine was to cut a small pump station in the side of the hole at a depth of 250 feet, so that water from the surface zone above could be collected at that point and pumped to the surface.

The ground formation penetrated by the Cary mine borehole proved less favorable to drilling than that at the Zenith mine. It comprised fractured granite and greenstone in which several dike intrusions 5 to 50 feet thick were encountered. The hole tended constantly to drift. At a depth of about 725 feet it became necessary to excavate the sides of the hole sufficiently to permit installation of a concrete guide lining for the purpose of correcting the direction of the hole. The hole continued to drift, however, but further drastic corrective measures were unnecessary.

Detailed comparative figures were not available, but on a basis of elapsed calendar days from start to finish of the respective boreholes the average of progress was 5.6 feet per day at the Zenith mine and 4.1 feet at the Cary. Work at both mines was on a continuous 24-hour-day basis. The slower rate of the Cary mine was due to unfavorable ground conditions and to greater depth of hole.

Cost figures were not available. The per-foot cost given for the Zenith mine borehole in the paper by Newsom and Haselton[4] is $12.16 for labor and supervision and $7.34 for power and materials. These figures do not include rental charges by the patent owners on drilling equipment used or the cost of installing same, the latter being estimated at $10,000. The cost per foot of sinking the hole at the Cary mine was not available, but obviously it is considerably higher than at the Zenith mine.

As far as known, the first large-diameter, reamed churn-drill hole in the Lake Superior district was sunk at the Hiawatha No. 1 mine in 1940. Two other large-diameter holes were sunk at the same mine in 1945, and a third is being sunk. The three completed holes are 30 inches in diameter; one is 1,004 feet deep, one 380 feet, and the third 525 feet. The hole now being sunk will be 36 inches in diameter and about 700 feet in depth for the present although it is planned to deepen it from time to time to keep pace with mining operations, the final expected depth being about 1,900 feet. Backfill material is dumped through the holes, either directly into worked-out stopes or is delivered to the stopes from the holes with scrapers.

In 1942, work on a reamed churn-drill hole to serve as an intake air shaft was started at the Sherwood mine. It was completed in March 1943. The hole is 48 inches in diameter to a depth of 487 feet, 30 inches from thence to a depth of 930 feet, and 12 inches from that point to the bottom at 1,000 feet. It was intended to ream the hole to a diameter of 48 inches to the bottom, but the reamer broke and war priorities made materials for a new reamer unavailable for many months, so further reaming of the hole had to be abandoned.

An air fan was installed on a sublevel and a connection made to the hole at the 920-foot depth.

Work on a 15-inch-diameter churn-drill hole to serve as a pilot hole in sinking an air shaft was started at the Spies-Virgil mine early in 1945. It was completed at a depth of 560 feet early in June 1945. The steeply dipping rock formation penetrated was comprised of hard and soft layers, which caused the drill bit to jam frequently and retarded progress considerably. Further delay was caused by the inability to "hole through" underground because the hole had left a straight course. The hydrofluoric and gelatin methods were used in surveying the hole, which permitted the determination of a true course for a connecting drift in the mine.

It is planned to enlarge the 15-inch hole to a diameter of 7 feet. It will then serve as an air shaft and emergency exit.

The six churn-drill holes enumerated were drilled by the same contractor under respective contracts. The general contract price on holes in ground such as encountered in the Iron River district is $1 per foot of finished hole per inch of diameter, where the hole width is 30 inches or more. For holes of smaller diameter, the rate is somewhat less. For hole depths in excess of 1,000 feet, the contract rate would be increased, probably on a sliding scale as the depth of hole increased. It is believed that holes ranging in diameters to 48 inches can be sunk to 2,500 feet or more by this method.